Effects of Stress Relief on the Mechanical Properties of Orthodontic Wire Loops

David F. Lane, D.D.S., M.S.
Robert J. Nikolai, Ph.D.

Looped archwires are employed routinely, within many treatment philosophies, in clinical orthodontic retraction procedures. The formation of such loops takes the wire material well beyond its elastic limit and, upon completion of the bending process, leaves the wire in a residual stress state beyond that existing in the as-received condition. This study sought to discover if stress relief is a necessary or advisable procedure in the over-all preparation of certain orthodontic retraction loops and to determine whether or not wires of differing sizes and vendors and different loops exhibit variations in mechanical behavior depending upon the type of stress-relief process.

The mechanical properties of elastic stiffness and elastic range were determined for a number of loop, wire-size, and vendor combinations. Loops subjected to electric-current and furnace stress-relief processes were compared with counterparts having received no stress relief following formation from straight wire. Clinical implications have been deduced from the bench-test results and suggestions made pertaining to the need or desirability to stress relieve, when and by what process.

Review and Interpretation of Previous Research

The use of various orthodontic wire loops to accomplish treatment objectives has been studied by a number of investigators over the past four decades.[1-8] Collectively, these researchers have cited three mechanical properties of loops as particularly important to the practitioner: 1) elastic stiffness (the ratio of change in induced force to change in amount of activation at low force levels); 2) elastic limit load (the force at which, upon unloading, permanent deformation or "set" with respect to the initial, passive loop configuration is detected); and 3) elastic range (the amount of activation possible without exceeding the elastic limit of the loop). General agreement exists with the following statements concerning looped wires: 1) no loop exerts a truly continuous force; 2) loops may be contoured to "open" or to "close" upon activation; 3) the use of any loop will result in reduced stiffness and greater range of the appliance because of the increased length of wire between the brackets; 4) the loop stiffness may be decreased by incorporating helices in the loop and/or by reducing the cross-sectional dimensions of the wire of the loop; and 5) the elastic range of a loop is increased if the loop is activated in the same direction as it was formed.

While austenitic stainless steel as a material reportedly cannot be substantially hardened (made more resilient) through heat treatment, research has shown that relevant mechanical property values of stainless steel orthodontic wire can be altered somewhat through a low-temperature stress relief. Experimentation has been conducted toward determination of the optimum temperature and time combination for the stress-relief heat treatment of stainless steel wire.[9-13] Investigators have commented on the directions and/or amounts of particular property value changes resulting from low-temperature heat treatment,[7,14,15] although disagreements exist among researchers regarding these changes and in the over-all effectiveness of such a heat treatment.

The placement of bends in a wire is a work-hardening process. In such a procedure the level of stored strain energy in the wire is increased and, as mentioned previously, a residual stress pattern resulting from taking the material beyond its elastic limit remains in the now looped wire. A stress-relief process is, in general, one that transfers energy to the material as a means of releasing energy from it, the process executed in such a fashion as to result in a net reduction in the residual stresses and in the stored energy level within the material. This may be accomplished through a furnace heat-treatment with, in the case of stainless steel wire, the furnace temperature and the time at temperature carefully controlled to produce the desired effect without markedly reducing the corrosion resistance of the wire. Three to five minutes in a furnace maintained at 700 to 900 degrees Fahrenheit has proven appropriate; the higher the temperature, the less the time in the furnace.

While stress relieving via the furnace has been commonplace in dentistry for years, other means exist to transfer energy and initiate the process. Recently, devices have been marketed by orthodontic/dental suppliers which provide energy input to the wire, transferred by means of an electric current. The wire in place in the device completes a circuit, a transformer and rheostat increase and control the current input, and the circuit is charged for only a few seconds. The dental literature apparently contains no studies evaluating this particular stress-relief procedure, which in this research was compared with furnace heat treatment and a control (no stress relief following loop formation).

Materials and Procedures

Wires chosen for this study were of sizes often employed in retraction procedures in edgewise orthodontics. The rectangular wires of two vendors were selected which, even though materially identical, possessed clinically detectable mechanical property differences, apparently originating with their separate wire manufacturing (drawing) processes. Obtained on the open market were samples of .019-inch by .026-inch and .021-inch by .027-inch TP "Rounded Edgewise" and .019-inch by .025-inch and .021-inch by .025-inch Unitek "Standard Permachrome" wires.

The loops to be formed were selected to include in the sample both "opening" and "closing" loops with and without helices. Specifically chosen, also in part because of their widespread use, were the tear-drop, the simple reverse-closing, and the helical reverse-closing loops (Fig. 1). All loops were bent using typical orthodontic pliers and clinical techniques, except that for standardization a template of "master" loops was initially prepared. Each test specimen formed was immediately checked against the template by superposition for size and shape conformity. All loops were seven millimeters in height and the tear-drop, the simple reverse-closing, and the helical reverse-closing loops contained 15, 18, and 25 millimeters of wire, respectively.

Eighteen acceptable loops of each of the twelve wire-loop combinations were subdivided into six-specimen subsamples. Within each wire-loop combination six specimens were heat treated in a Huppert Deluxe Furnace at 850°F for 3.5 minutes, six under-

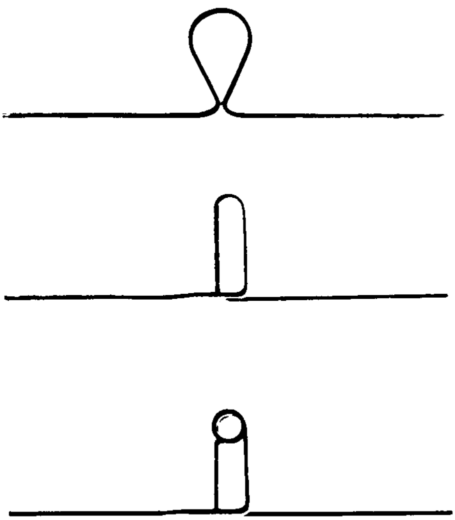

Fig. 1 The three loops used.

went electric-current stress relief using the Orthotreat unit marketed by Dental Corporation of America, subjecting the individual loops to seven amperes for four seconds, and six received no stress relief whatever following formation. The furnace temperature and time were chosen following evaluation of previous research. The current level and time combination was a result of a pilot study and was determined primarily from the production of the straw-colored wire surface in the shade seen in the treated wires taken from the furnace.

In a typical test, using an experimental apparatus designed and manufactured specifically for the laboratory quantification of mechanical properties of orthodontic wires, force readings were taken at half-millimeter increments of activation. Beyond one millimeter the loop was deactivated after each force reading to determine at what point the elastic limit was exceeded (as evidenced by permanent set); when this was reached, no further data were collected from the specimen. The elastic stiffness for a specimen was obtained by averaging the ratio of force to activation readings below the elastic limit. With each tear-drop loop, in determining stiffness, any residual force (compressive, between the legs of the loop) was quantified initially and subtracted from all subsequent force readings.

Mean elastic stiffness and range values were obtained for each of the thirty-six subsamples and analyses of variance were carried out via a digital computer toward statistical comparisons of the dependent-variable values according to wire size, vendor, loop, and stress-relief process.

Discussion of Results

The main-effect differences in stiffnesses as provided by an analysis of variance were partially as expected; loops formed from the smaller wires were more flexible than those from the wires of greater cross-sectional dimensions and the Unitek wire loops were verified to be stiffer than those formed from the TP wire. However, the simple reverse-closing loop, despite the slightly greater length of wire incorporated in it, proved to be stiffer than the tear-drop loop. The helical reverse-closing loop was the least stiff of the three. The rank order, most flexible to stiffest, of the loops by stress relief was none to electric-current to furnace. All main-effect differences in stiffness were highly statistically significant ($p < .001$). The stiffness analysis of variance produced only one interaction, that between wire size and loop type, and judged weak because rank orders were unchanged from those of the main-effect comparisons. The mean stiffness values for the 36 subsamples are given in Table I.

The range analysis-of-variance summary also reflected highly significant differences in all four factors. Elastic

TABLE I

Mean Stiffness Values (in grams/mm.) for All Subsamples

Loop	*Stress Relief*	*TP* 19 × 26	*TP* 21 × 27	*Unitek* 19 × 25	*Unitek* 21 × 25
Tear-drop	None	365	576	448	594
	Electric	390	554	484	638
	Furnace	418	554	491	677
Simple Reverse Closing	None	436	588	500	726
	Electric	531	634	499	728
	Furnace	487	721	616	778
Reverse Closing with Helix	None	288	394	380	489
	Electric	352	458	414	483
	Furnace	368	435	418	502

TABLE II

Mean Range Values (in millimeters) for All Subsamples

Loop	*Stress Relief*	*TP* 19 × 26	*TP* 21 × 27	*Unitek* 19 × 25	*Unitek* 21 × 25
Tear-drop	None	1.7	1.3	1.8	1.4
	Electric	2.0	1.7	2.0	1.8
	Furnace	1.8	1.5	2.4	2.0
Simple Reverse Closing	None	1.9	1.8	2.6	2.0
	Electric	2.3	1.9	2.4	1.7
	Furnace	2.1	1.8	2.8	2.2
Reverse Closing with Helix	None	2.4	2.2	3.0	2.8
	Electric	2.7	2.8	3.2	2.9
	Furnace	3.2	2.7	3.3	3.0

ranges were greater for the Unitek than for the TP wires and, as expected, greater for the loops formed from wires of smaller cross-sectional dimensions. The rank order by loop type varied directly with the amount of wire in the loop; the rank order according to stress relief was for range identical to that for stiffness. Mean range values for all subsamples are presented in Table II. Again, just one interaction was significant, that between vendor and stress relief; because this interaction is judged to have clinical implications, with rank order differences present, the mean range values are given in Table III.

TABLE III

Significant Interaction: Vendor with Stress Relief

Mean Range Values in Millimeters

Stress Relief	*Vendor* *TP*	*Unitek*
None	1.88	2.26
Electric	2.21	2.30
Furnace	2.16	2.60

In undertaking a discussion of the results of this study from a clinical-implications standpoint, it is first convenient to establish several references. First, recall that the stiffness value enables the determination of the initial force magnitude from the amount of activation of the loop within the elastic limit and the deactivation rate of the loop. Taking suggested physiologically-proper values from Gianelly and Goldman,[16] bodily retraction of a maxillary incisor pair (central and lateral) requires approximately 325 grams and for a mandibular incisor pair about 275 grams; addition of the canines to the segments increases these values to about 500 and 425 grams per side, respectively. Second, the clinician, using wires of the sizes employed in this research, is often reluctant to activate these loops more than 1.5 millimeters (with the possible exception of the helical loop); the practitioner avoids inelastic behavior, excessive force levels, and potential loss of control intraorally. Third, with respect to the dependent variables of this study, for argumentative purposes minimum clinically-significant differences in stiffness and in range values were somewhat arbitrarily set at 50 grams per millimeter and one-half millimeter, respectively. Before concentrating on matters of stress-relief influence, noteworthy is the apparent fact that direction of loop activation, with respect to the direction of loop formation from straight wire, can affect stiffness more substantially than length of wire in the loop. Although incorporating three millimeters less wire, the teardrop loop was found to possess an over-all average stiffness approximately 90 grams per millimeter less than that of the simple reverse-closing loop. Similar results were obtained by Engel.[17]

Mean results of this study indicated stress relieving by the electric-current procedure increased loop stiffness by 6.6 percent; the increase in stiffness by relieving residual stresses in the furnace was 11.8 percent. While the mean increases by both methods were statistically significant with respect to the control, the main-effect difference in resulting stiffnesses between the two procedures was not statistically significant. In terms of the clinically-significant difference figures established above, a review of Table I leads to the deductions that 1) generally the furnace stress relief produces a significant stiffness increase, 2) often the electric current procedure results in a significant increase, and 3) when the electric-current method produces a significant stiffness increase, the difference between resulting stiffness values via the two stress-relief procedures is insignificant.

The mean percentage increases in range by stress relieving by the electric-current and furnace methods were found to be 9.1 and 13.9, respectively; again, while both were significantly different, statistically, from the mean range of the control, the differences between the mean ranges of the stress-relieved subsamples were insignificant. Viewing Table II and recalling the clinical "standard" of difference chosen for range (0.5 millimeter), it is difficult to describe a pattern throughout in simple terms other than to note that a clinically significant difference generally exists between the control (as-formed) and one or both of the stress-relief processes. However, again noting the interaction (Table III) emphasizes the important point that the effect of type of stress-relief procedure on the as-formed loop depends, to some extent, on the as-received condition of the 18-8 stainless steel wire.

By increasing both the elastic stiffness and the range of the loop through stress relief following formation, the loop is made more resilient; although not measured directly, the elastic strength, by reason of its relationship with stiffness and range, must also experience an increase. While the effects of stress relief on three of these four important properties are positive, focus must be on the impact of stress relief on stiffness in view of the aforementioned, suggested force levels for retraction and the rather narrow limits of activation (1.0-1.5 millimeters) apparently employed by the typical clinician using these looped wires. Specifically, note in Table I that, for an activation of just 1.0 millimeter, *none* of the stress-relieved loops will produce an initial force under the suggested value to bodily move an incisor pair. Also noteworthy is the result that, although increasing the elastic range is inherently good, with only two wire-loop combinations are the as-formed ranges below 1.5 millimeters (Table II); for most clinicians perhaps only these two would be candidates for range extension through stress relief.

Generalizing, both the electric-current and furnace techniques of stress relief have been shown to increase the resilience of stainless steel wire loops, with the furnace method usually being somewhat more effective. The increased stiffness, however, is detrimental to simple loops formed of heavy wire. If choosing to stress relieve in certain situations, because of the initial investment and substantial time involved with the furnace procedure, the practitioner might be well-advised to try the electric-current device.

Conclusions

The purposes of this investigation were to determine 1) if stress relief is a necessary or desirable procedure in the preparation of certain orthodontic retraction loops and 2) whether or not wires of differing sizes and vendors and different loops exhibit variations in mechanical behavior depending upon the type of stress-relief process.

Stress relieving the various loops generally resulted in greater resiliences, reflected in increases in both stiffness and range in nearly all relieved subsamples compared to the as-formed loops. The increased resiliences were statistically independent of wire size and vendor and whether the loop was contoured to open or to close upon activation. Stiffnesses were generally raised a greater amount through furnace stress relief than by the electric-current procedure; the comparative increases in range with respect to the as-formed loops were found to be dependent upon wire vendor.

The following conclusions seemingly can be drawn from this research and probably reasonably extrapolated to other stainless steel wires and loops formed therefrom:

1. Stress relieving, in increasing the elastic range of the loop, is in itself helpful to the clinician in situations where maximum activation is restrained by the elastic limit of the loop.
2. Stress relieving, in increasing the elastic stiffness of the loop, leads to a higher initial force magnitude for a given activation level and a larger drop in loop force per unit of deactivation. For loops having stiffness values comparable to those evaluated in this research, this is definitely an undesirable property-value change if keeping retraction forces at physiologically-proper levels is an objective.
3. All effects considered, stress relieving the particular loops chosen for this study probably is not practical from a clinical standpoint; however, for other, more flexible loop configurations, the process might be worthwhile.
4. Differences in results between the two stress-relief procedures were not substantial clinically, but were generally found dependent upon the as-received conditions of the wires. Prac-

titioners who choose to stress relieve in certain instances might be led to use the electric-current procedure, owing to its comparative ease and low cost, but experimentation with both methods is suggested with the various vendors' wires under consideration for the particular case and mechanics.

Department of Orthodontics
Saint Louis University Medical Center
3556 Caroline Street
St. Louis, Missouri 63104

REFERENCES

1. Paulich, F.: Measuring of orthodontic forces. *Am. J. Orthod.* 25:817-849, 1939.
2. Stoner, M. M.: Force control in clinical practice. *Am. J. Orthod.* 46:163-186, 1960.
3. Burstone, C. J., Baldwin, J. J. and Lawless, D. T.: The application of continuous forces to orthodontics. *Angle Orthod.* 31:1-14, 1961.
4. Newman, G. V.: A biomechanical analysis of the Begg light archwire technique. *Am. J. Orthod.* 49:721-740, 1963.
5. Jarabak, J. R., and Fizzell, J. A.: *Biophysical Considerations of Orthodontic Forces, Technique and Treatment with the Light-Wire Appliances.* St. Louis, Missouri, C. V. Mosby Company, 1963.
6. Weinstein, S.: Minimal forces in tooth movement. *Am. J. Orthod.* 53:881-903, 1967.
7. Thurow, R. C.: *Edgewise Orthodontics,* Third Edition, St. Louis, Missouri, C. V. Mosby Company, 1972.
8. Chaconas, S. J., Caputo, A. A., and Hoyashi, R. K.: Effects of wire size, loop configuration, and gabling on canine retraction springs. *Am. J. Orthod.* 65:58-66, 1974.
9. Backofen, W. A., and Gales, G. F.: The low temperature heat treatment of stainless steel for orthodontics. *Angle Orthod.* 21:117-124, 1951.
10. Funk, A. C.: The heat treatment of stainless steel. *Angle Orthod.* 21:129-138, 1951.
11. Kemler, E. A.: Effect of low-temperature heat treatment on the physical properties of orthodontic wire. *Am. J. Orthod.* 42: 793, 1956.
12. Howe, G. L., Greener, E. H. and Crimmins, P. S.: Mechanical properties and stress relief of stainless steel orthodontic wire. *Angle Orthod.* 38:244-249, 1968.
13. Marcotte, M. R.: Optimum time and temperature for stress relief heat treatment of stainless steel wire. *J. Dent. Res.* 52:1171-1175, 1973.
14. Kohl, R. W.: Metallurgy in orthodontics. *Angle Orthod.* 24:37-52, 1964.
15. Ingerslev, C. H.: Influence of heat treatment on the physical properties of bent orthodontic wire. *Angle Orthod.* 36:236-247, 1966.
16. Gianelly, A. A., and Goldman, H. M.: *Biologic Basis of Orthodontics,* Philadelphia, Pennsylvania, Lea and Febiger, 1971.
17. Engel, E. L.: A force-activation comparison of retraction loops used with the "018" and "022" bracket assemblies. Master's Thesis, Saint Louis University, 1977.

The Angle Orthodontist

A magazine established by the co-workers of Edward H. Angle, in his memory . .

Editor: Arthur B. Lewis.

Business Manager: Silas J. Kloehn.

Associate Editors:
Alton W. Moore, Morse R. Newcomb, Robert H. W. Strang.

Vol. L No. 2 April 1980